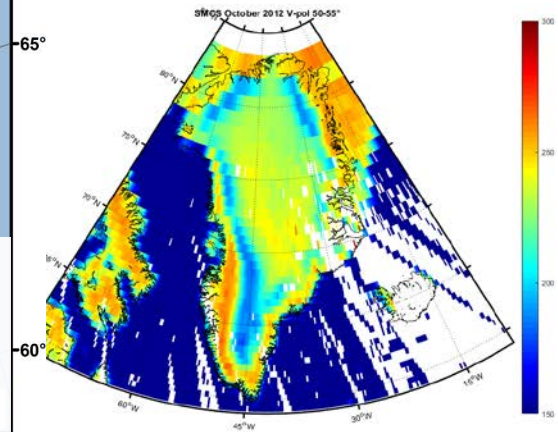
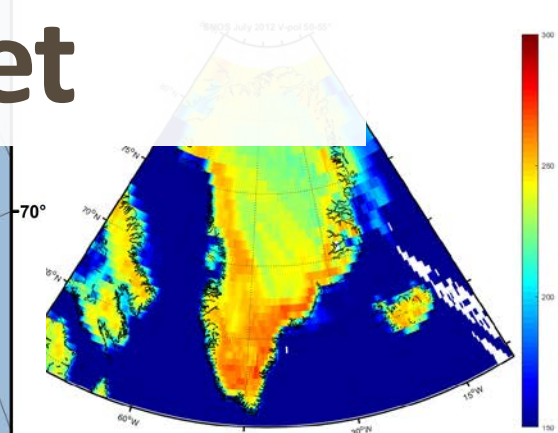
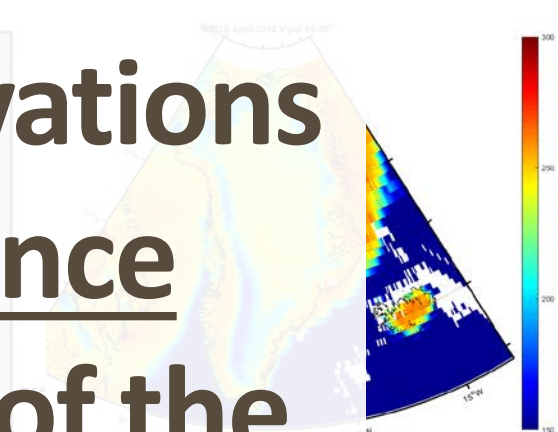


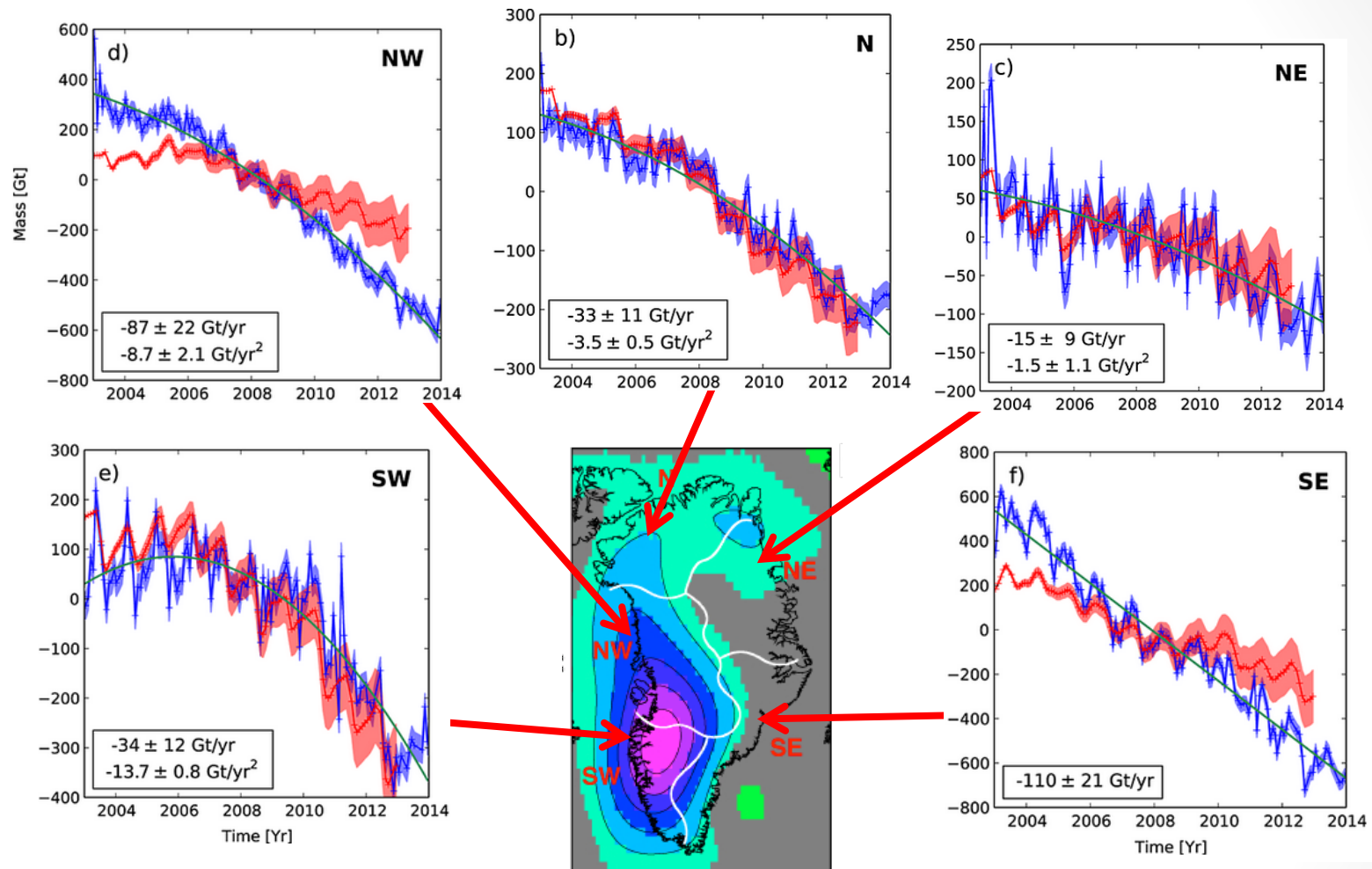
Upscaling in situ observations to surface mass balance estimates and models of the Greenland ice sheet



Mike MacFerrin
CIRES, University of Colorado
CESM LIWG Meeting, 9 Feb 2016



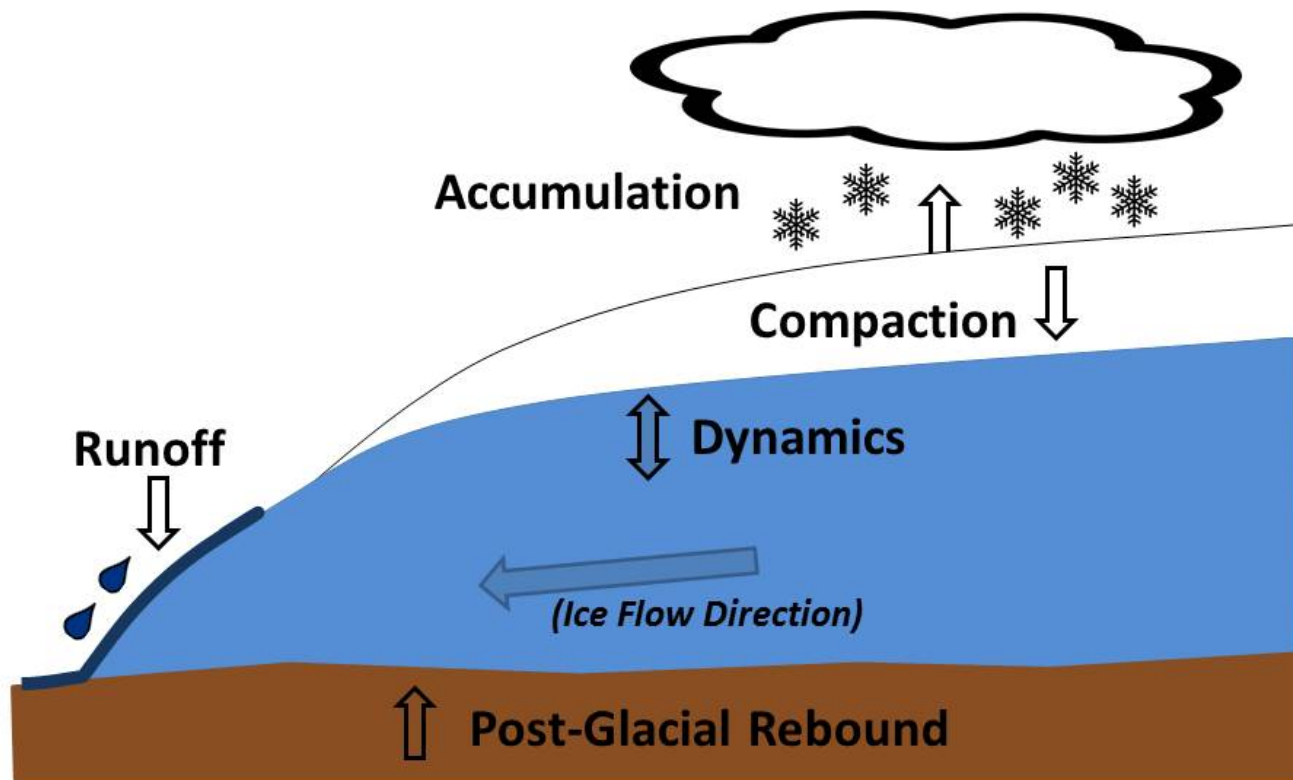
Greenland Surface Mass Balance, (2002-2014)



- **Surface Mass Balance (SMB)** accounts for **68% of mass loss** and **79% of acceleration** in Greenland, 2002-2014
- SMB is currently the **dominant mechanism** of mass loss

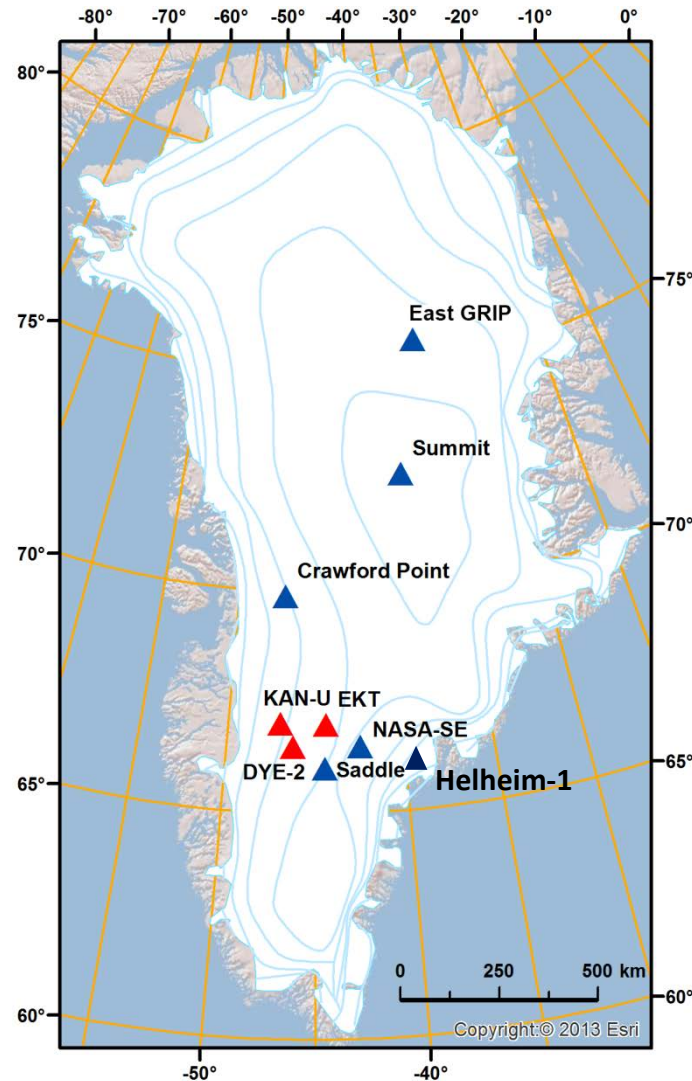
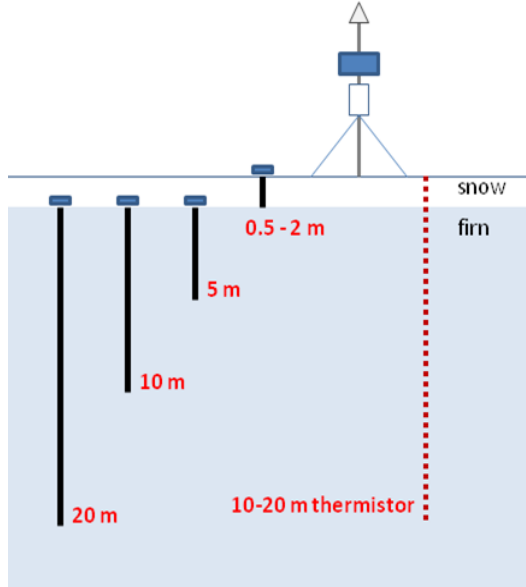
Firn Densification

- A primary uncertainty in ice sheet altimetry



Firn Densification

- Firn Compaction Verification and Reconnaissance (FirnCover)



Community Firn Model

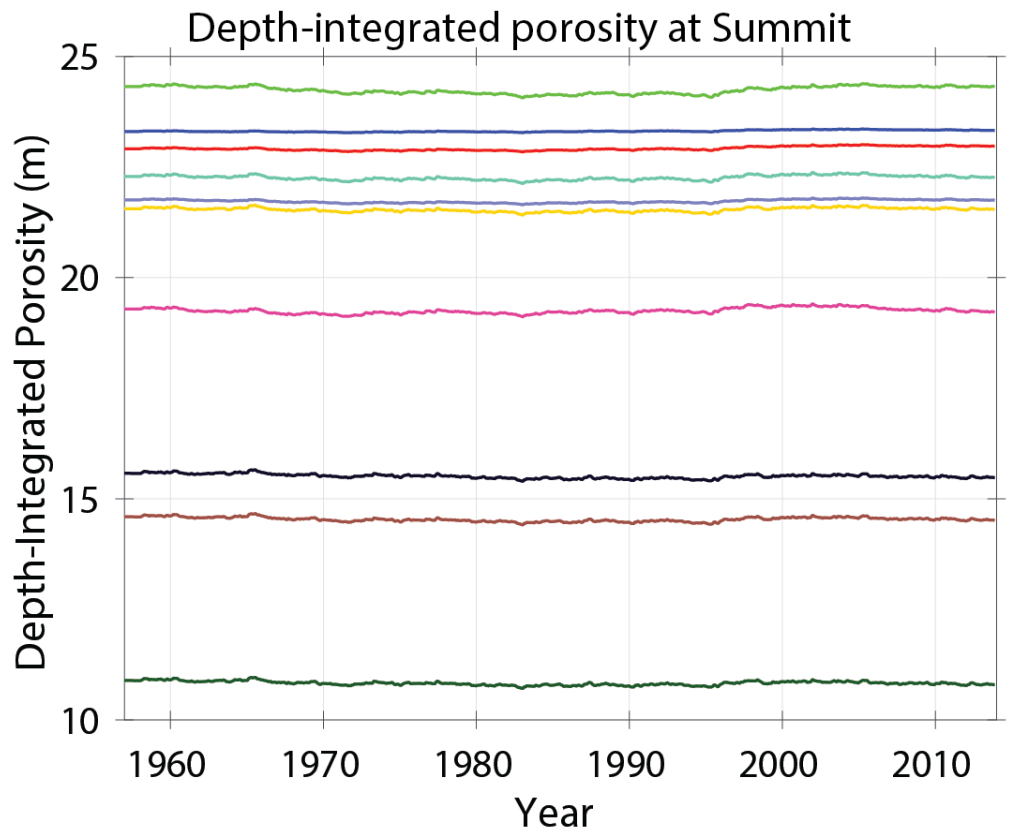
- Vertical compaction models from published literature

Herron & Langway, 1980	J. Glaciology, stress-based solution	Goujon et al., 2003	JGR Atmospheres
Herron & Langway, 1980	J. Glaciology, analytic solution	Barnola et al., 1991	Tellus B
Essery et al., 2013	Advances in Water Resources	Ligtenberg et al., 2011	The Cryosphere
Cummings et al., 2013	U. Montana Snow, Ice & Climate	Simonsen et al., 2013	J. Glaciology
Arthern et al., 2010	J. Geophysical Research	Li & Zwally, 2011	Annals Glaciology

- Most make steady-state climate assumptions

CFM Results at Summit, Greenland

- Forced with 1958 – 2013 temperature and accumulation (RACMO)
- Total porosity differs up to 220%



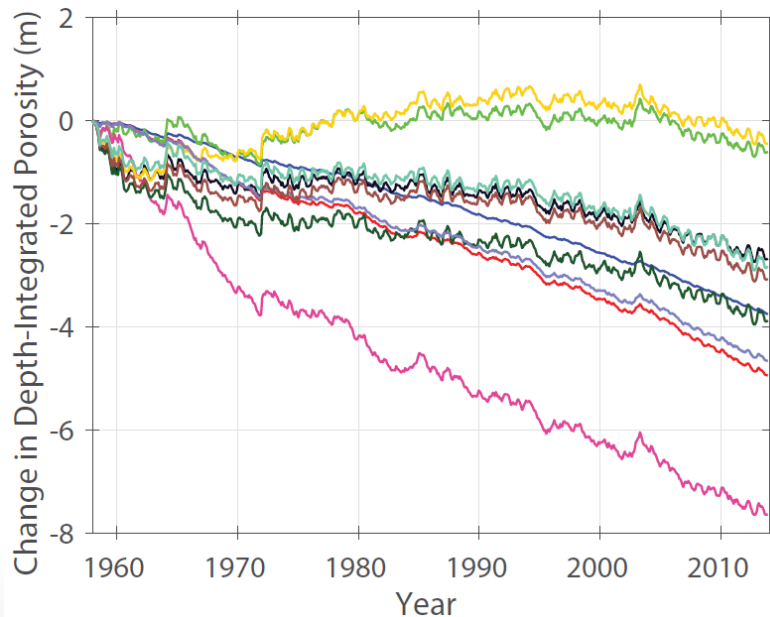
Max Stevens, University of Washington

Firn Model Initialization

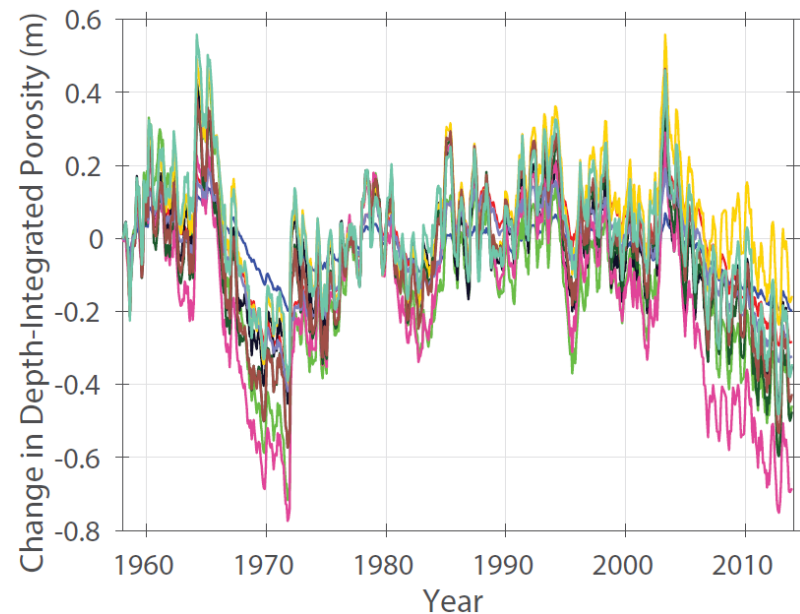
- Compare firn models forced by identical current climate
- Extremely sensitive to initialization

NASA-SE

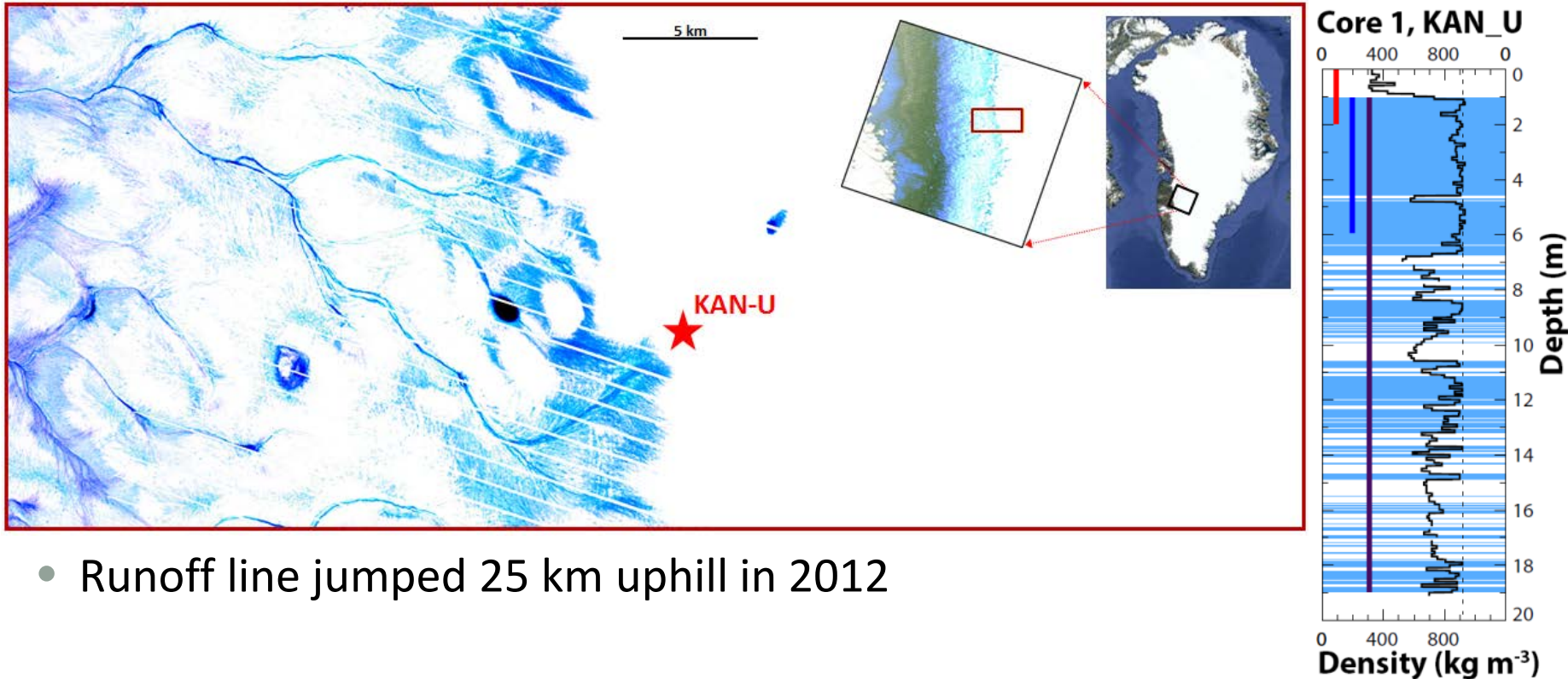
Initialized 800 years, **mean**
temp & accum 1958-2013
from RACMO



Initialized 800 years,
looped temp & accum
1958-1978 from RACMO

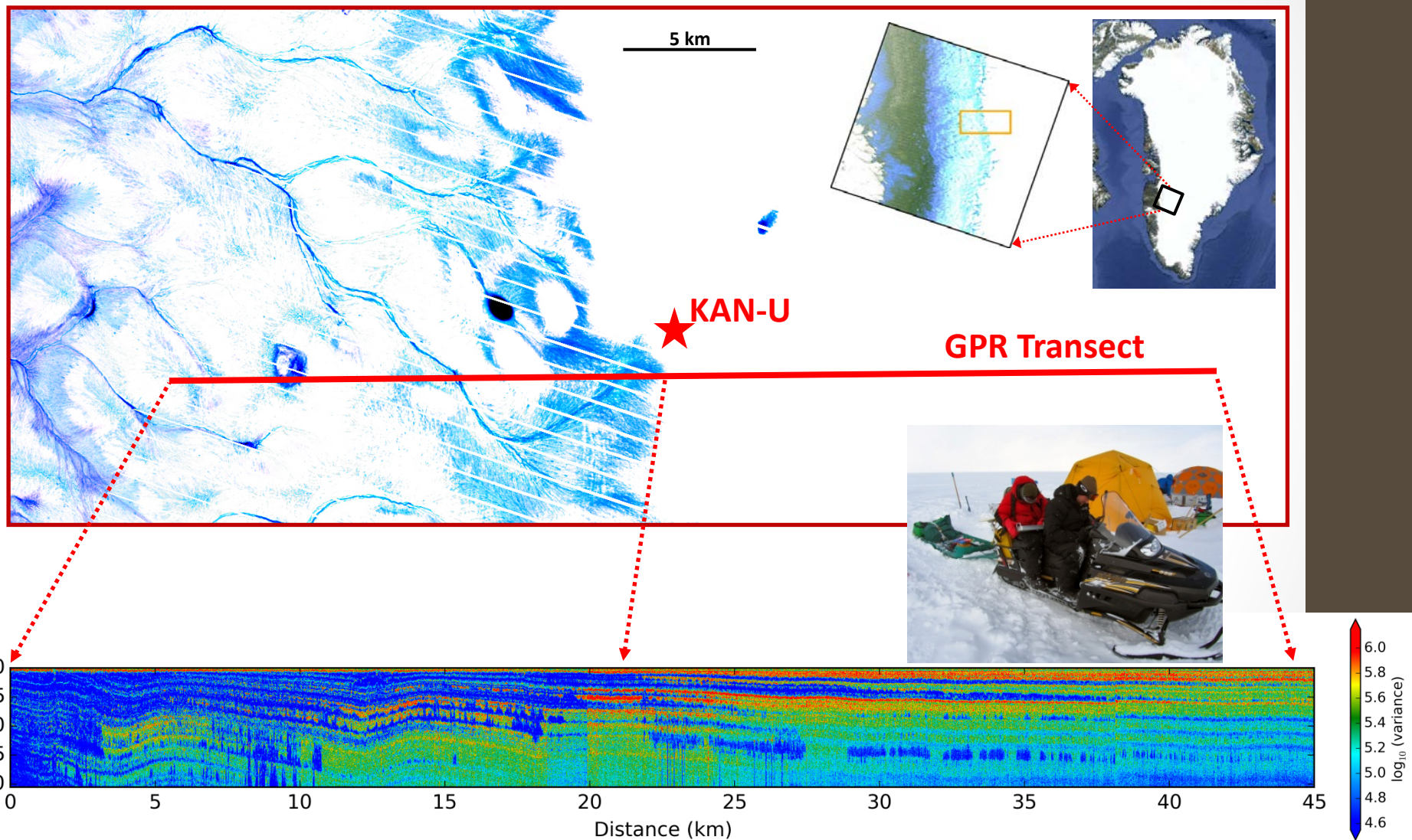


Shallow Firn Saturation



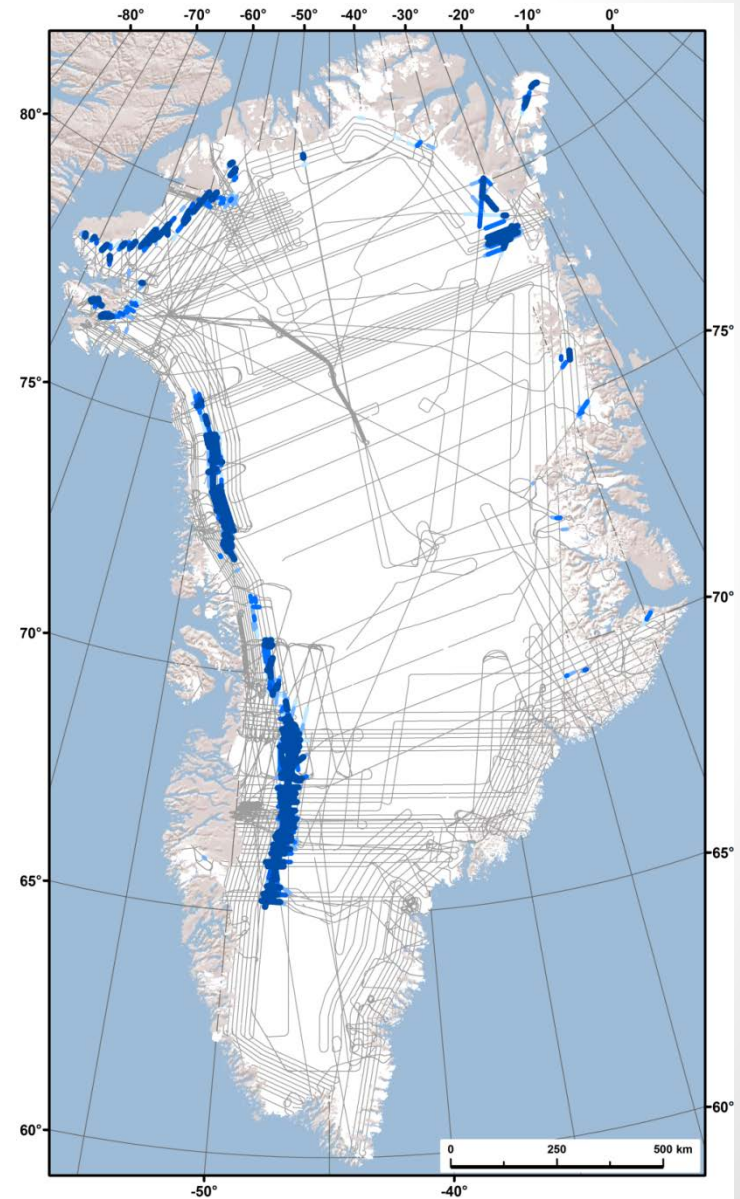
- Runoff line jumped 25 km uphill in 2012
- Shallow firn was saturating in successive “big” melt years (2002, 2005, 2007, 2010), which “primed” the firn for runoff

Mapping ice lids with GPR



Mapping Ice Lids with IceBridge

- Perched lids (>1 m thickness) span 60,000 km²
- Firn can saturate rapidly
- Runoff can migrate rapidly uphill
- **In 2012**, Ice lids in SW Greenland added 11±4% to regional runoff



Early saturation modeling

Solving for the ratio (M/C), we obtain

$$\frac{M}{C} \geq \left[\frac{c}{L} T_f + \left(\frac{\rho_{pc} - \rho_c}{\rho_c} \right) \right] \left[1 + \left(\frac{\rho_{pc} - \rho_c}{\rho_c} \right) \right]^{-1} \quad (\text{A2})$$

Substituting typical numbers for density and temperature for Arctic surface snow at the start of the melt season (e.g., $T_f = -15^\circ\text{C}$ and $\rho_c = 0.3 \text{ g cm}^{-3}$), M/C takes the value 0.697. This number turns out to be quite insensitive to reasonable variations in T_f and ρ_c , and for a wide variety of firm conditions, the necessary condition for runoff can be stated simply as

$$\frac{M}{C} \approx 0.7$$

Pfeffer, Meier & Illangasekare (1991), GRL

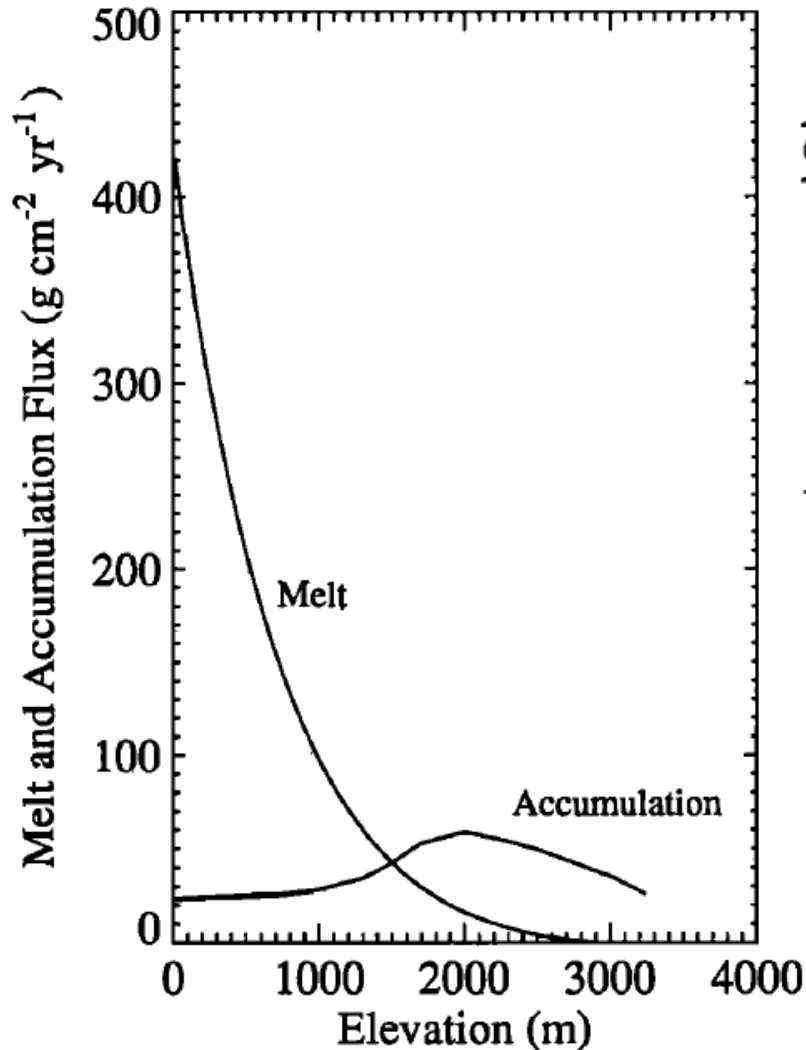
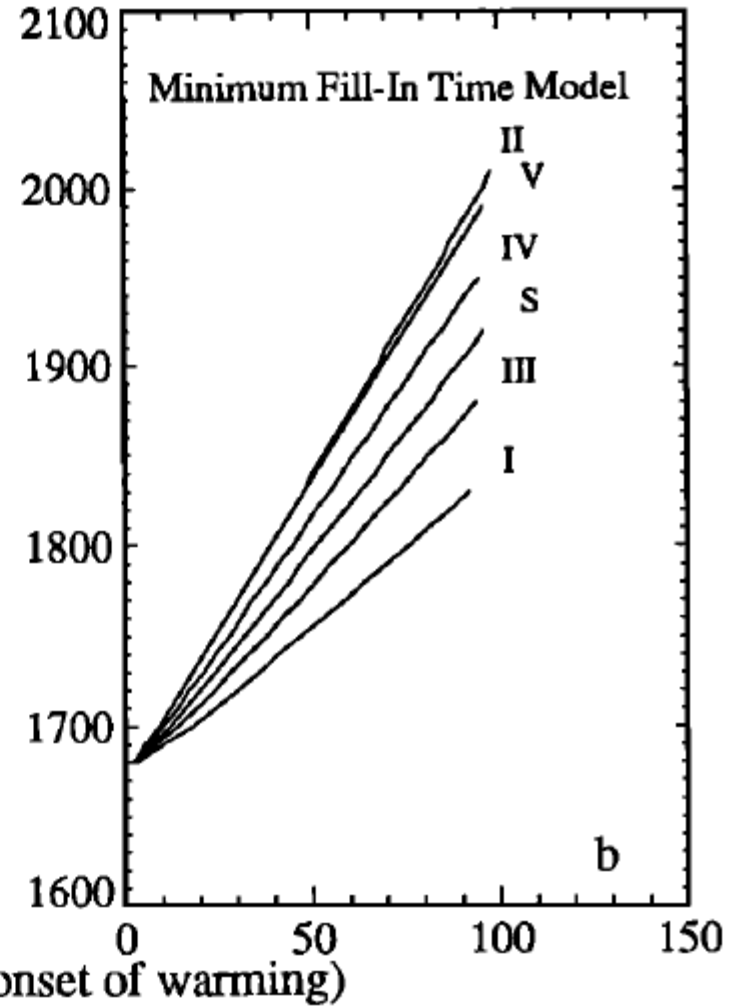
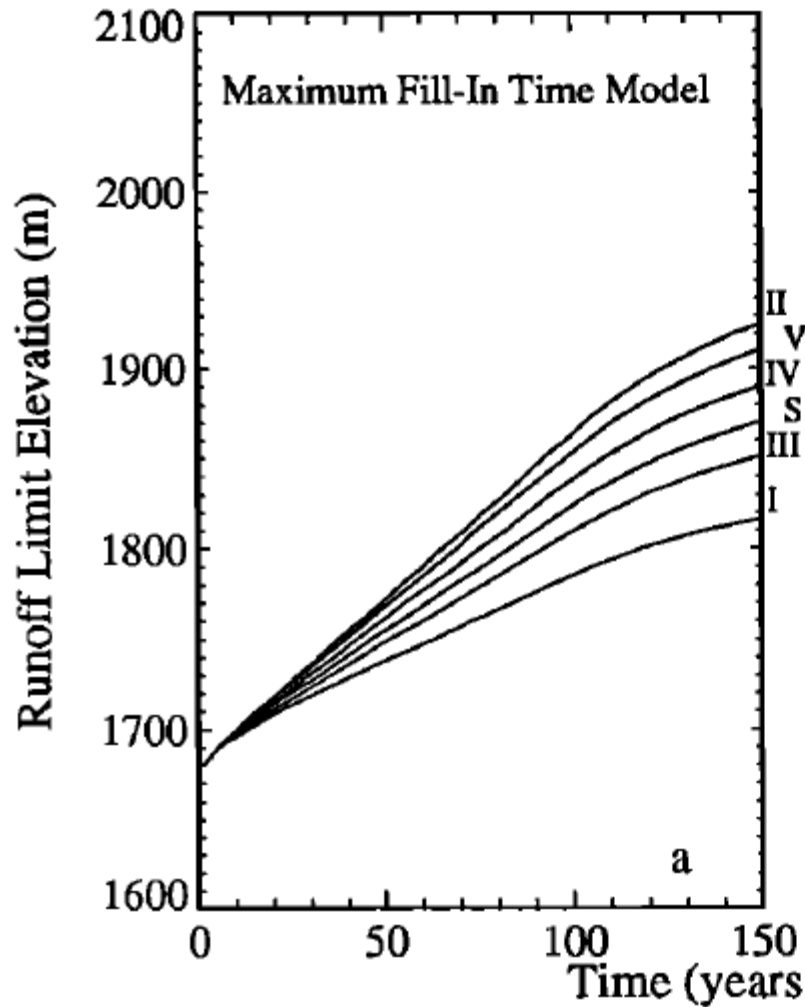


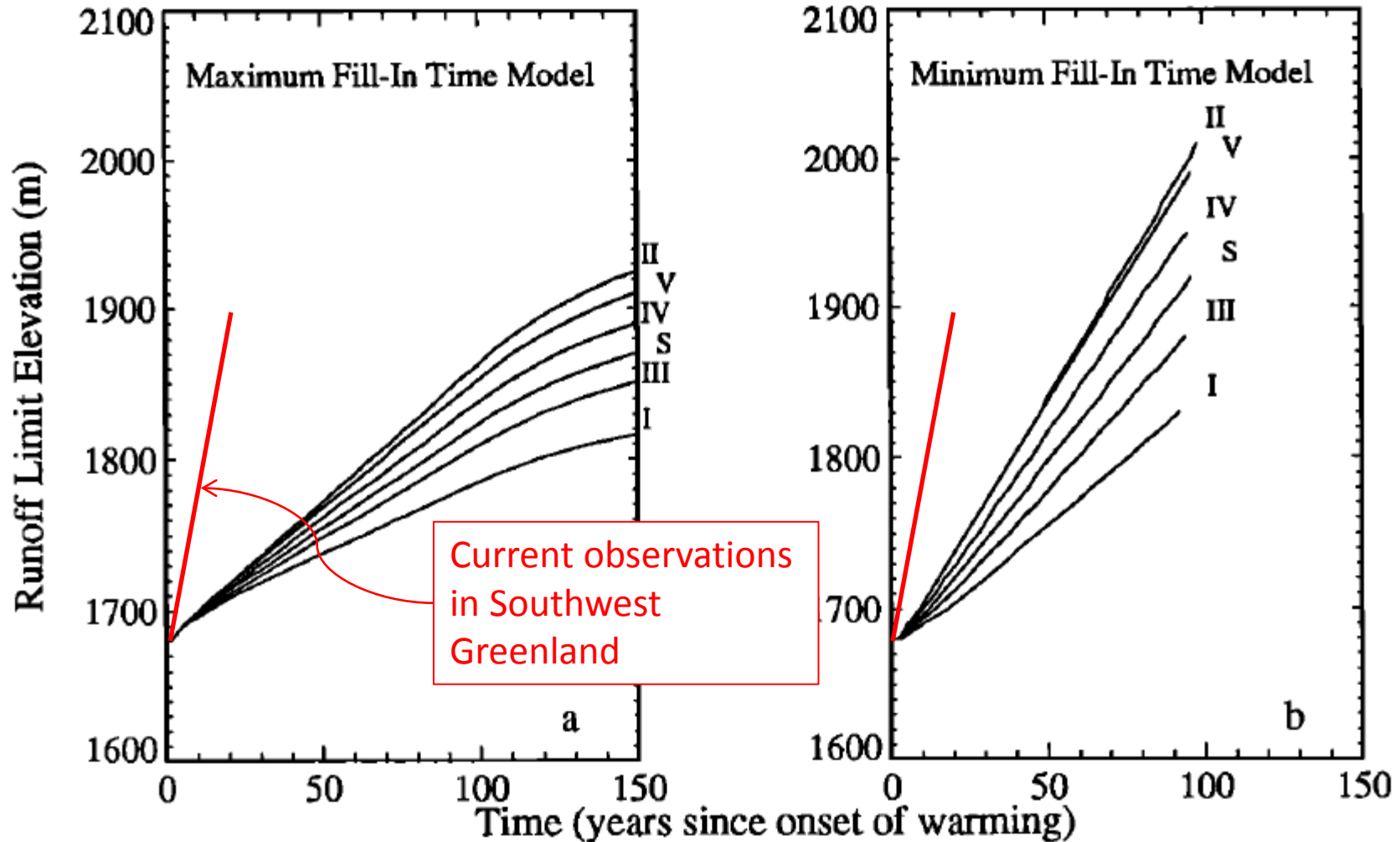
TABLE 1. Parameters for Future Climate Scenarios

Climate Model	$\Delta T, ^\circ\text{C}$	$\Delta c/c$	Variation From Standard Model
S	4	0.10	
I	3	0.10	1°C cooler
II	5	0.10	1°C warmer
III	4	0.15	50% wetter
IV	4	0.5	50% drier
V	4	0.0	no change in accumulation from present

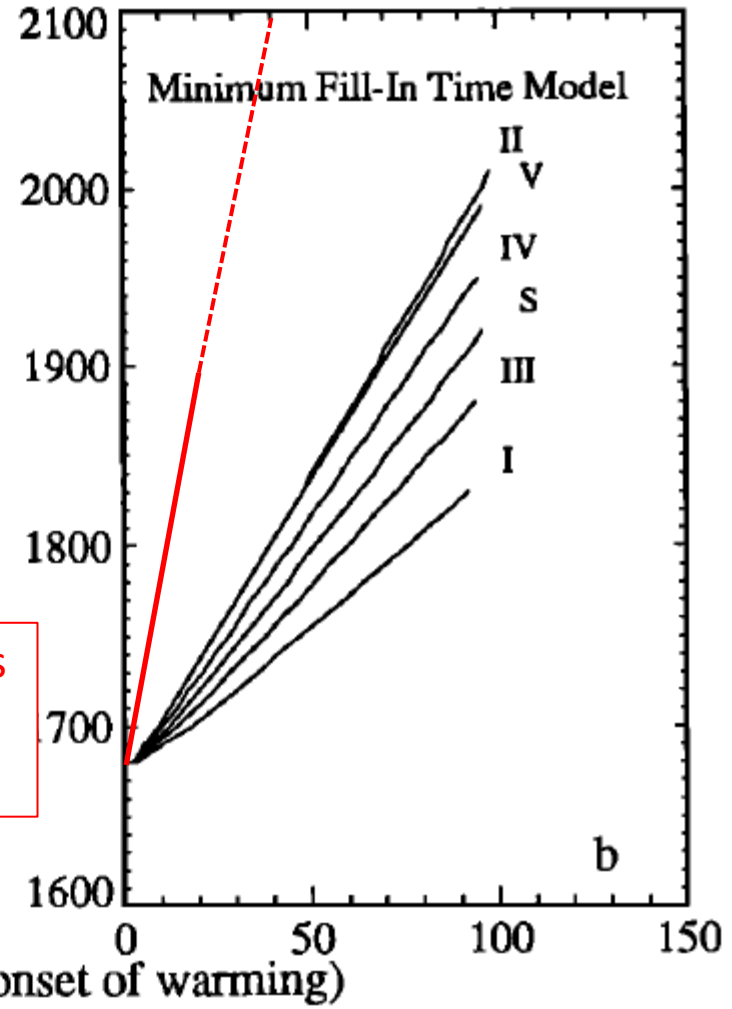
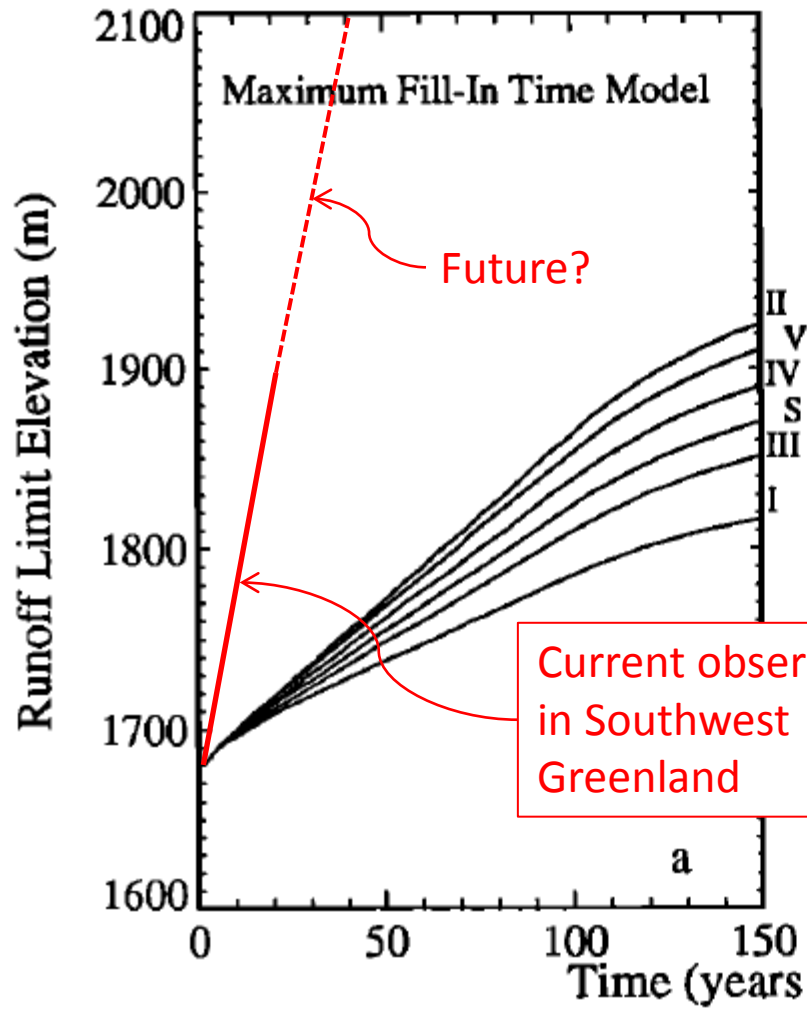
Early Saturation Modeling (cont'd)



Early Saturation Modeling (cont'd)

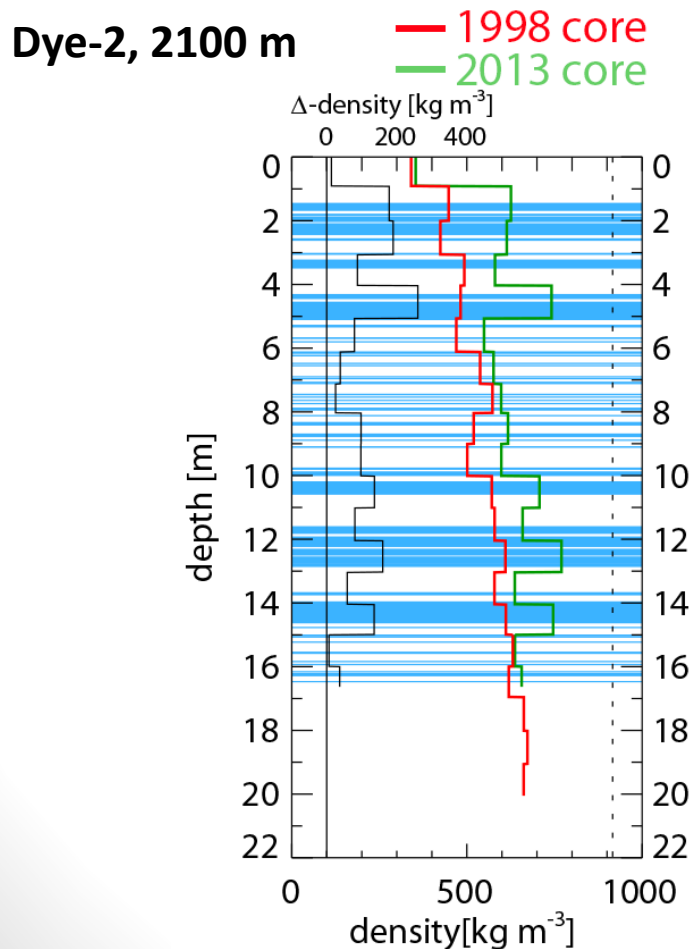


Early Saturation Modeling (cont'd)



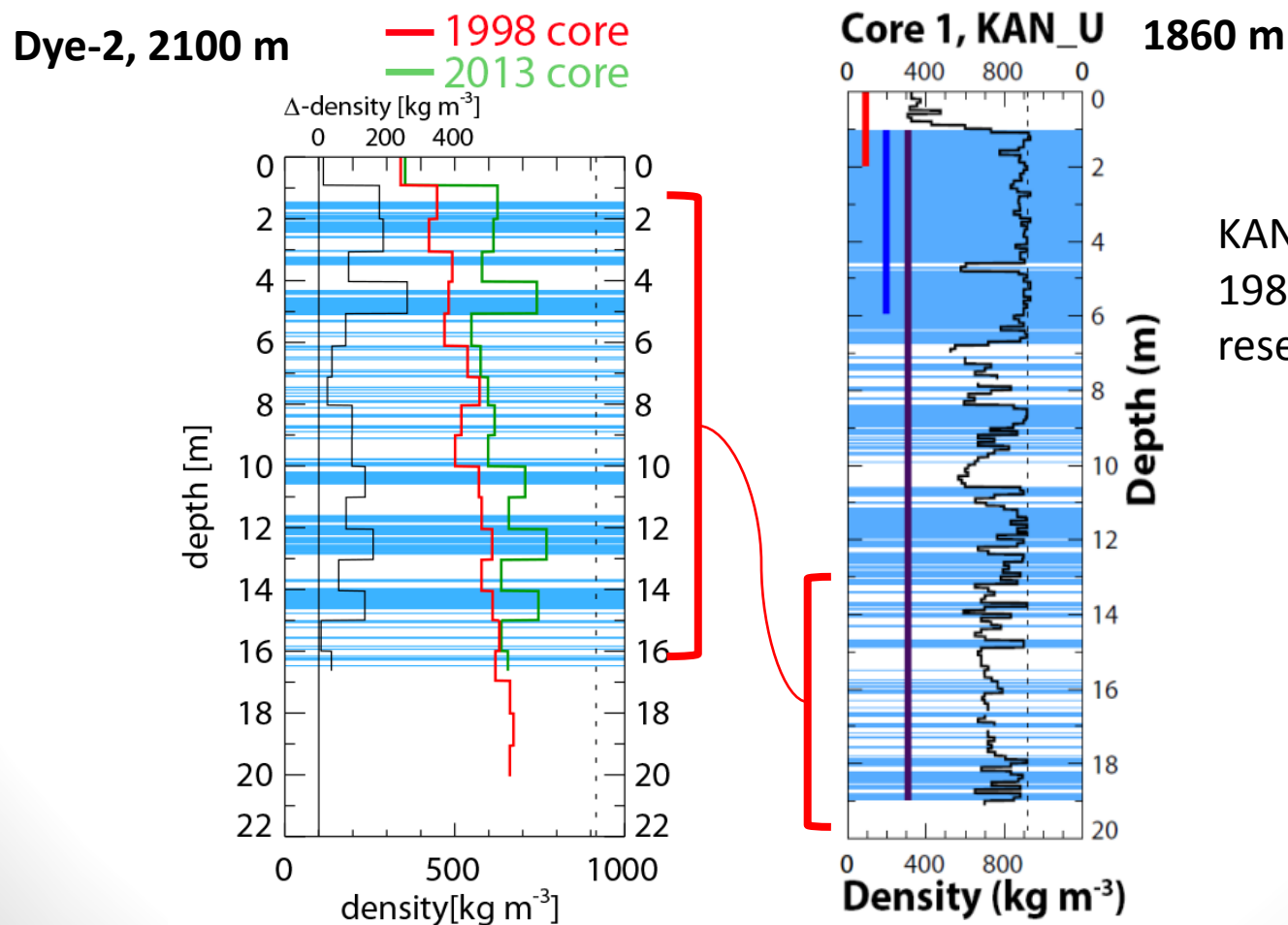
Dye-2 Firn Cores, 2100 m.a.s.l.

- 1998 – less than 5% ice content
- 2013 – greater than 25% ice content in top 16 m



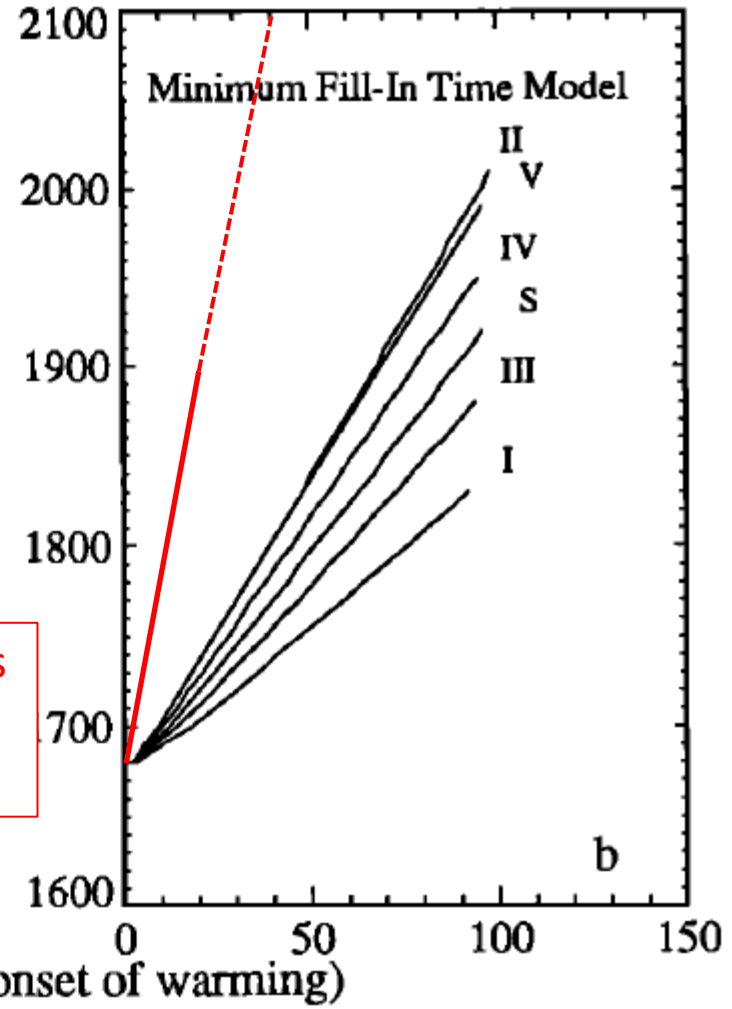
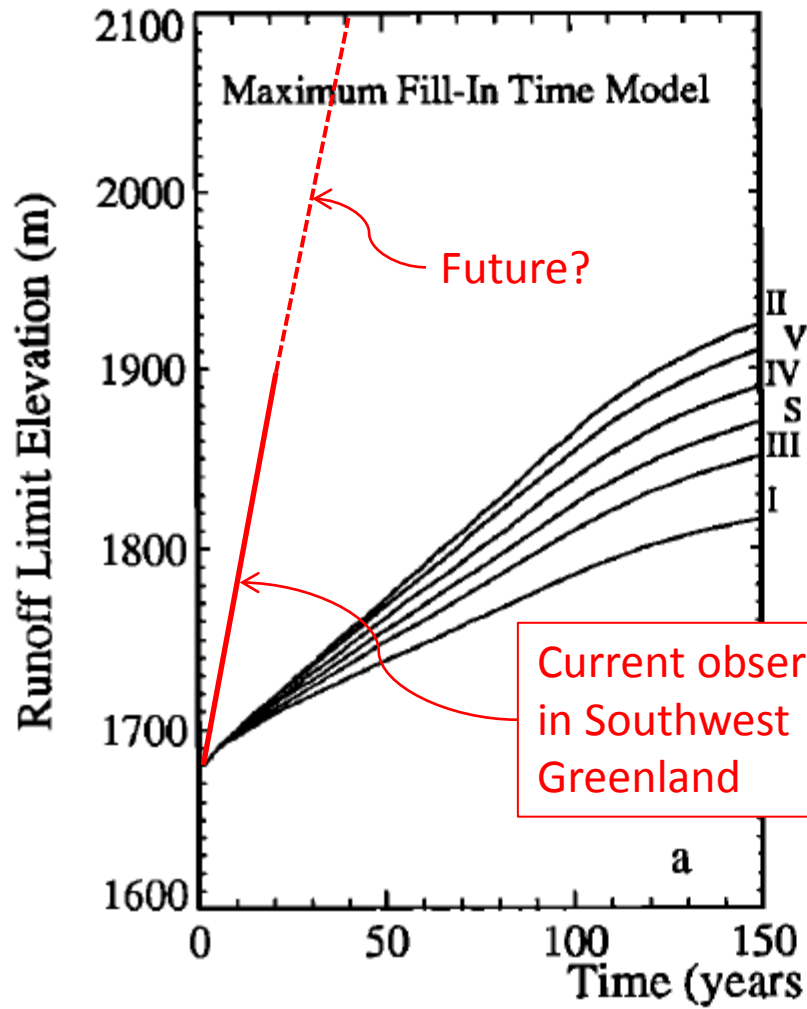
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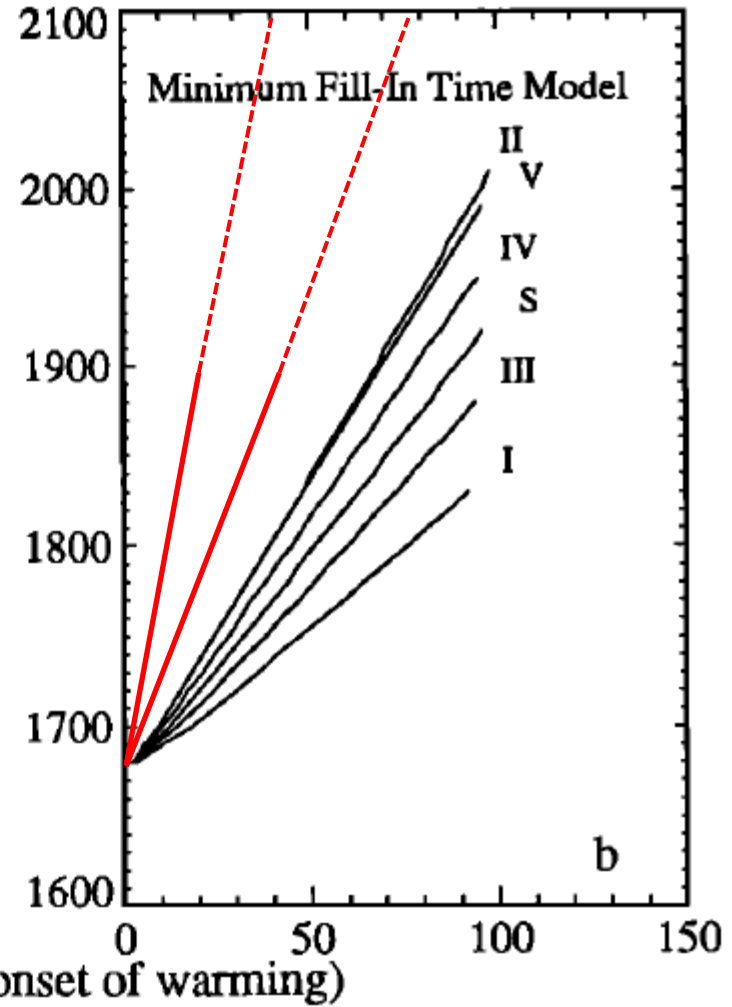
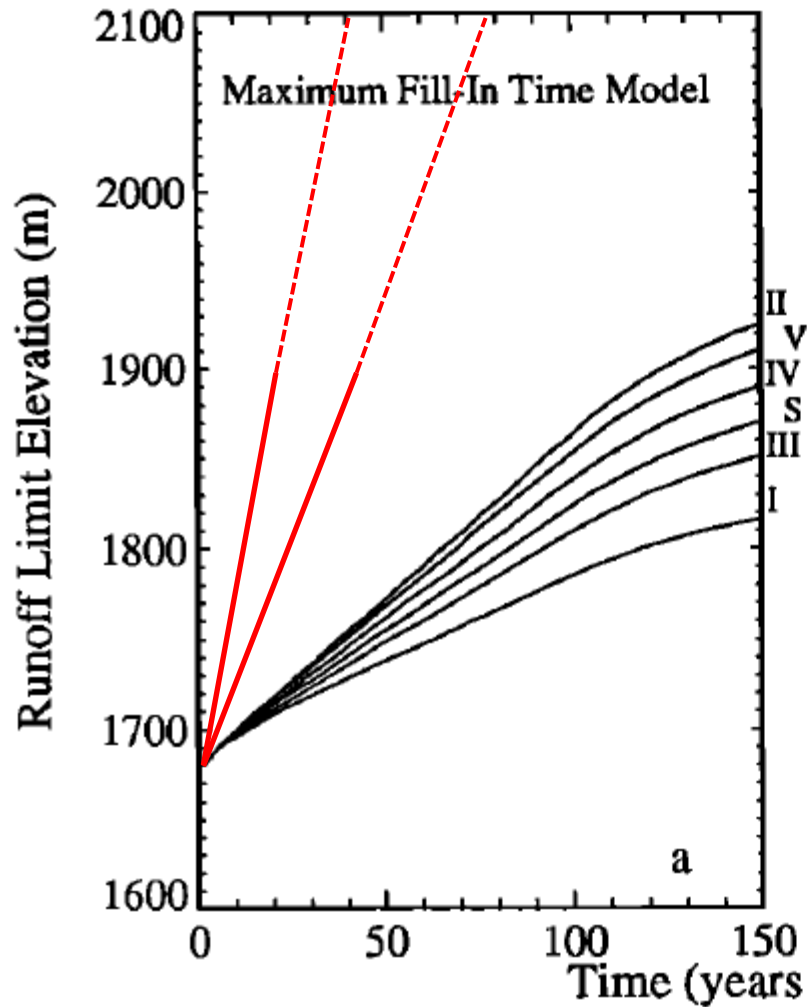


KAN-U firn from
1980-1990s
resembles Dye-2 now

Early Saturation Modeling (cont'd)



Early Saturation Modeling (cont'd)



Conclusions

- As temps rise, Surface Mass Balance (SMB) now dominant in Greenland
- Firn has “memory”
 - Initialization and ensemble strategies crucial for short-term simulations
- Community firn model (CFM) density intercomparisons are under way
- SMB exhibits high variability and non-linear “threshold” behaviors
- Spatial resolution is an issue (always is!), thoughtful parameterizations are necessary

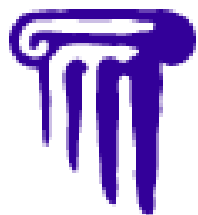
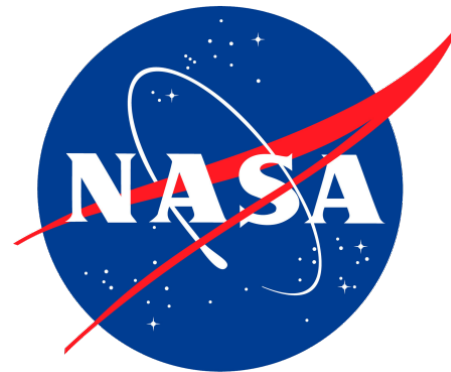
Conclusions

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- Spatial resolution is an issue (always is!), thoughtful parameterizations are necessary
- I’d like to contribute (a job?)

Questions?



University of Colorado
Boulder



UNIVERSITY OF
WASHINGTON